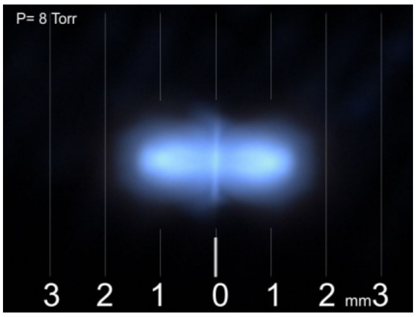

A study of the laser produced plasma in stationary gases at low pressures

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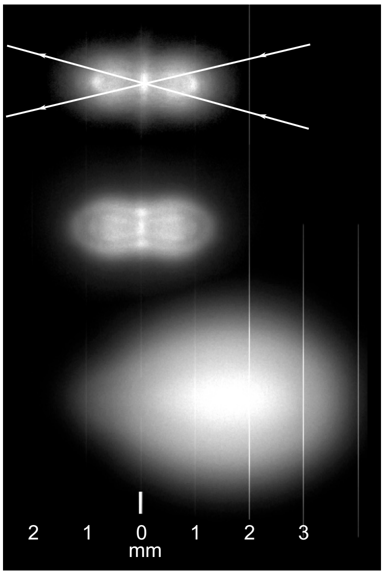
Before to commence on experiments with the supersonic microjet target, **A PRELIMINARY EXPERIMENTAL CAMPAIGN** with the laser plasma in stationary gases at low pressures had been undertaken. Pressure range – 1 Torr to 1 atm – corresponded to gas densities expected in the jet – 10^{17} to 10^{19} cm^{-3}. Gases used were H_2, He, Ar, and Xe. Nd:YAG laser was applied, $\lambda = 1.06$ µm, E_{las} was up to 1 J.



LONG EXPOSITION SPARK PHOTOGRAPHS reveal some specific features of the low pressure laser plasmas:

- plasma body has a symmetric, elongated form which follows, in general, to the form of the laser beam;
- spark length rises as the pressure increases, amounting to 3-5 mm;
- complex spatial spark structure is clearly seen;
- at higher pressures, part of the spark faced to the laser dominates, absorbing major part of the laser energy.

On the photo:

- *above – Ar, P = 23 Torr, $I_{abs}/I_0 = 2\%$, laser beam geometry is shown;*
- *in the middle – Xe, P = 11.5 Torr, $I_{abs}/I_0 = 1.7\%$;*
- *below – Xe, P = 96 Torr, $I_{abs}/I_0 = 93\%$.*

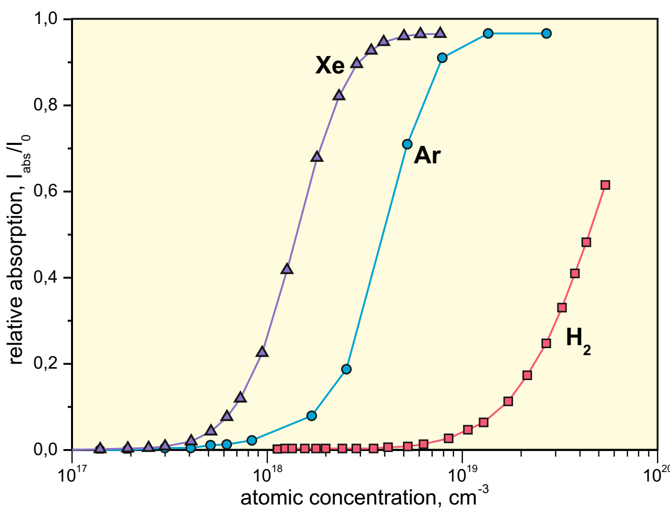
The laser is on the right of the sparks; the focus point is at 0-coordinate in all the cases.

ABSORPTION OF THE LASER ENERGY AND PLASMA TEMPERATURE.

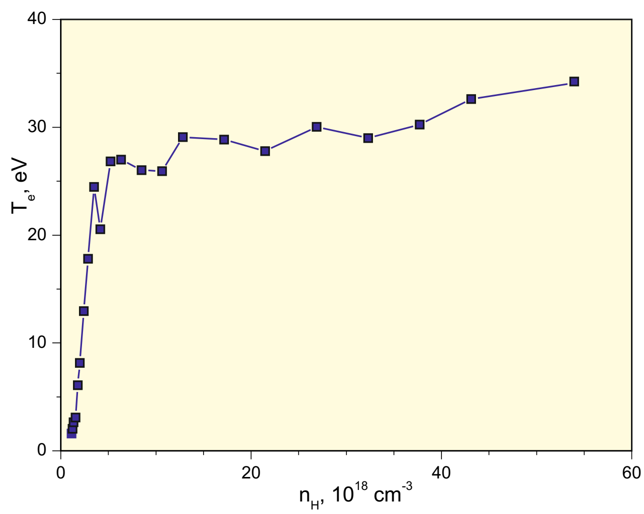
Values of the absorption coefficient, µ, can be easily deduced from the measured absorption, $I_{abs}/I_0 = \exp\{-\mu x\}$.

$$\mu = \frac{4\pi e^2}{m_e c}\frac{n_e \nu_{ei}}{\omega^2} = \frac{4\pi e^2}{m_e c}\frac{n_e n_i \langle \sigma_{ei} V_e \rangle}{\omega^2} = \frac{16\pi^2 e^6}{(3m_e)^{3/2} c} L_C \frac{Z^3 n_i^2}{\varpi^2 (k_B T_e)^{3/2}}$$

Therefore, the plasma temperature, T_e, could be derived if the average ion charge, Z, were known.



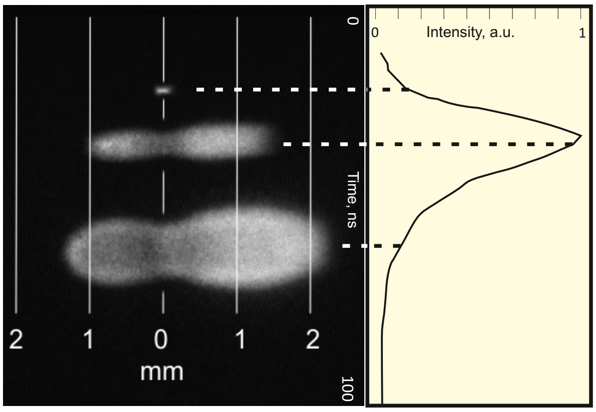
Absorption for 3 gases: Xe, Ar, H_2



Temperature of the hydrogen plasma (Z = 1).

In Xe laser plasmas, if Z is supposed to be from 9 to 11, the temperature turns out to be about 30 eV also.
In Ar plasma, if T ≈ 30 eV, the ion charge Z = 5-6.
Quasi constancy of the temperature at large variations of external parameters is very interesting feature of the laser plasmas.

EVOLUTION OF THE LASER PLASMA IN TIME

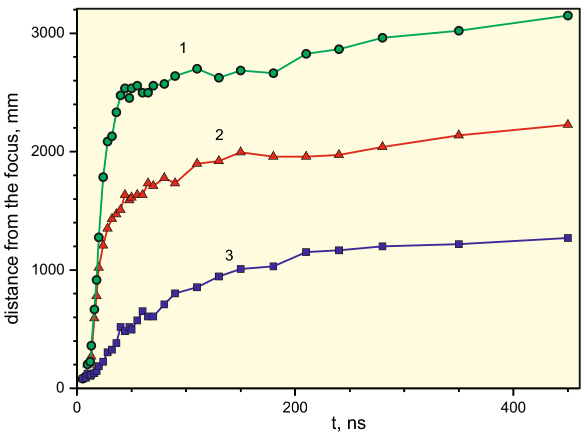


Snap-shots of the plasma spark in Ar.
P = 162 Torr, E_{las} = 535 mJ; I_{abs}/I = 75%.
Shot moments are shown in relation to the laser pulse waveform. BIFO K008 streak & uniform camera was used. Exposition – 1.8 ns.

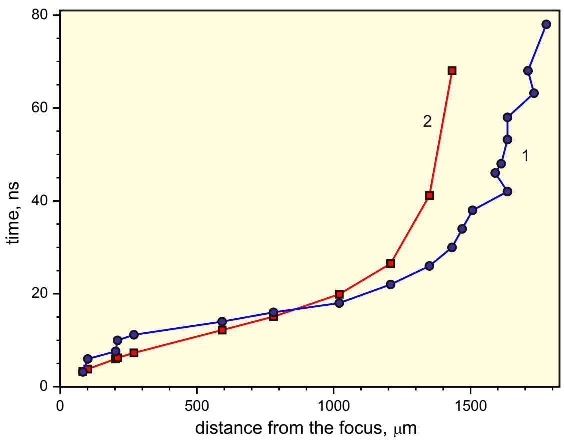
Velocities of the plasma expansion: under the laser energy effect $V_{driven} \approx 10^7$ cm/s, when and where the laser radiation does not exist V_{free} is from 10^6 down to 10^5 cm/s. Only V_{free} could be explained with shock waves.
Primary electrons born by the multiphoton ionization are cold (about 1 eV) and unable to excite/ionize atoms. They gain heat energy from the electromagnetic wave through collisions with atoms but intensity of the laser radiation goes down with distance from the focus, L. So, time of accumulation of the energy necessary for the ionization is:

$$\tau_i = \frac{E_i (kL)^2 m_e c\omega^2}{4e^2 W_{las}} \times \frac{1}{n_a \sigma_{ea} < V_e >}$$

Thus, the longer distance from the focus the later the gas luminosity appears. This looks like a light front travel to the both sides from the focus with a certain velocity. However, actually, neither particles nor energy move with that velocity – it is a sort of "phase" velocity, which is not restricted.



Plasma boundary motion in different directions from the focus:
1 – toward the laser;
2 – backward from the laser;
3 – across the beam in the focal plane.



Time of the plasma light appearance in a point on the beam axis vs. its distance from the focus:
1 – experiment (inverted curve 1 from the Fig. left);
2 – calculation.

CONCLUSION

At low gas densities, the plasma has symmetric relative to the focus, elongated form with lengths within the mm-range. The proposed mechanism of plasma stretching along the beam allows to define plasma length for any given laser pulse parameters and gas density distribution.
Deduced from the experiment plasma temperatures turns out to be close to 30 eV.

PUBLICATIONS IN JOURNALS

S. G. Kalmykov et al. Technical Physics Letters, to be published in 2011 (two articles).